Data Communication and Net-Centric Computing

COSC 1111/2061/1110

Lecture 5

Multiplexing

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Lecture Overview

- During this lecture, we will understand
  - Multiplexing
  - Frequency division multiplexing
  - Time division multiplexing
  - Statistical multiplexing

- Recommended reading
  - Chapter 8 (Stallings)

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Multiplexing

- Sharing of the communication channel by different source-destination pairs
- Provides better channel utilization
- Used in major signal transmission applications
- Examples: radio, TVs, telephone lines etc
- Simplest form
  - *n* inputs connects through a link
  - Link able to carry *n* separate channels of data
  - *n* outputs

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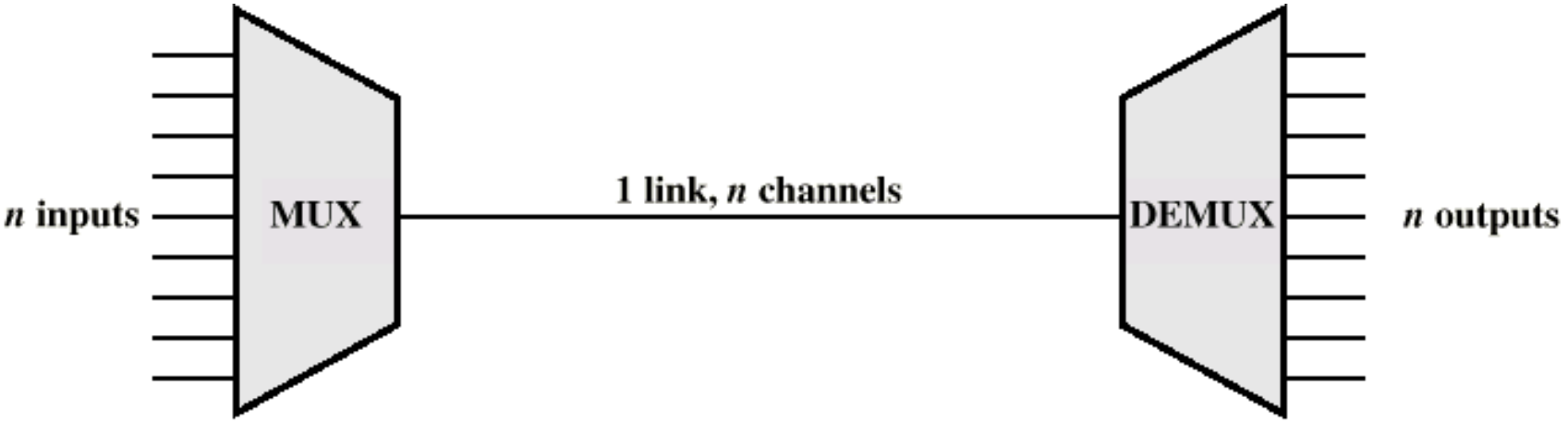
Multiplexing



N-Channel Multiplexing

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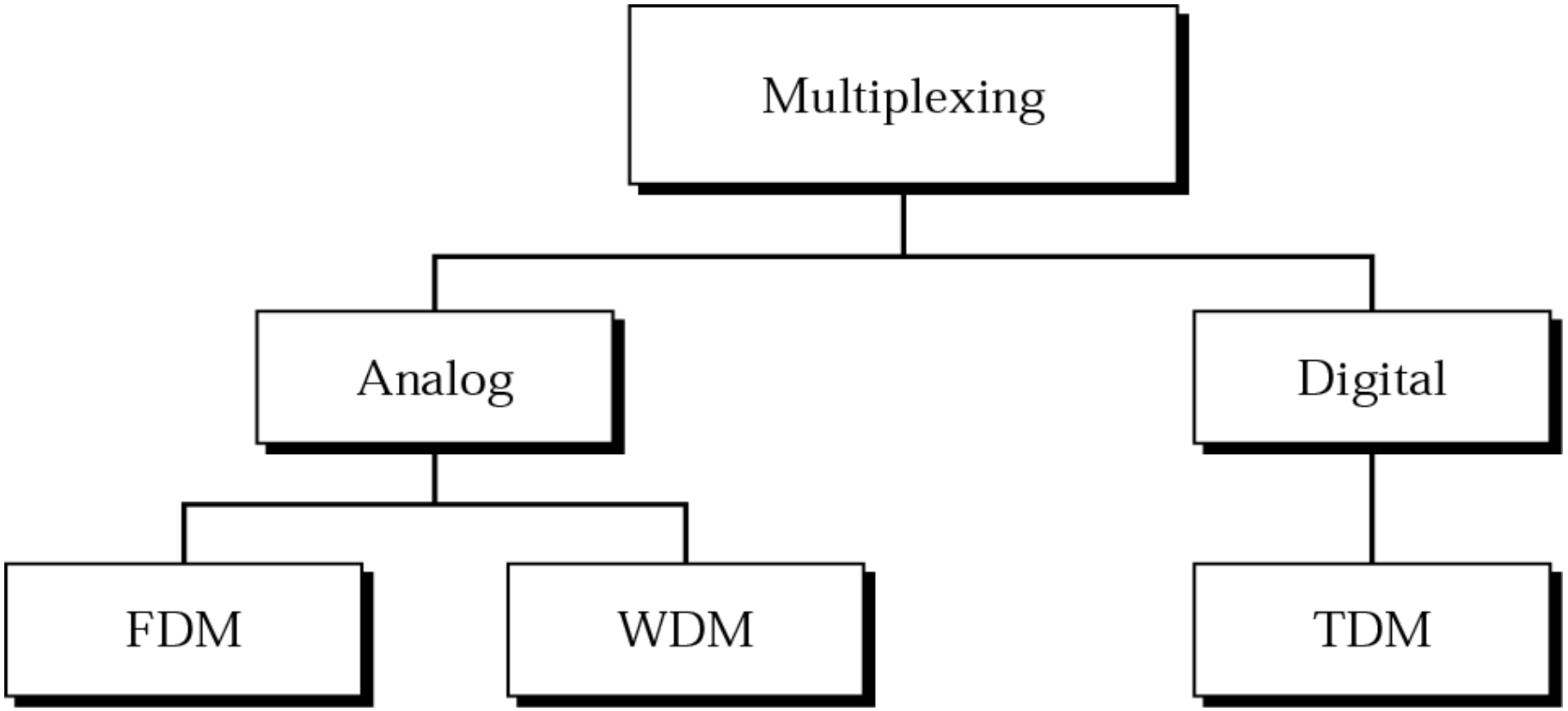
Categories of multiplexing



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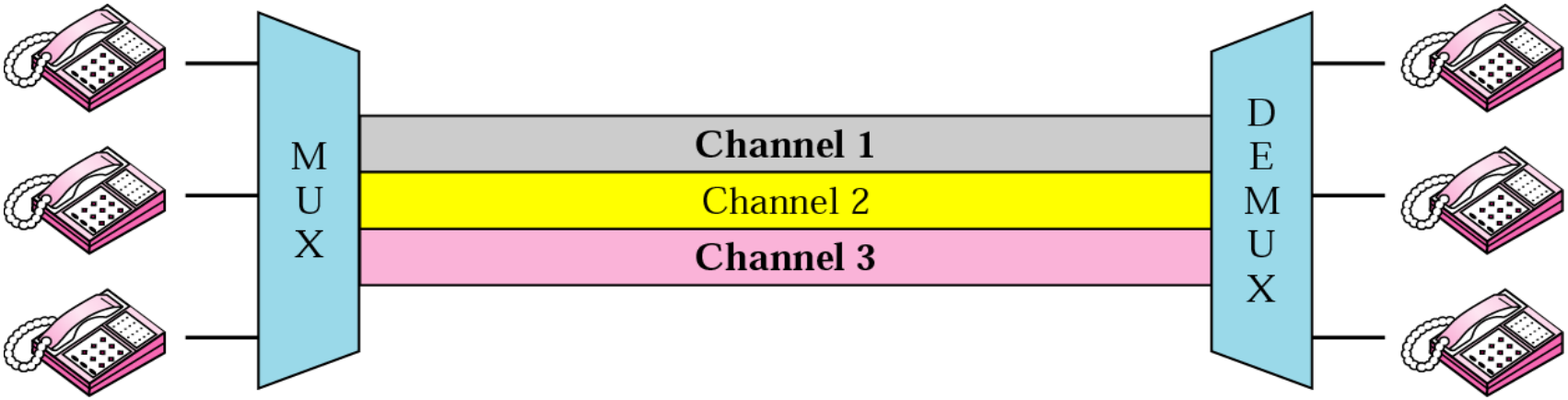
Frequency Division Multiplexing



- FDM is an analog multiplexing technique that combines signals.
- Number of signals can be carried simultaneously over a single medium
- Each signal modulated onto a different carrier frequency
  - Each modulated signal requires a certain bandwidth centred around its carrier frequency (channel)

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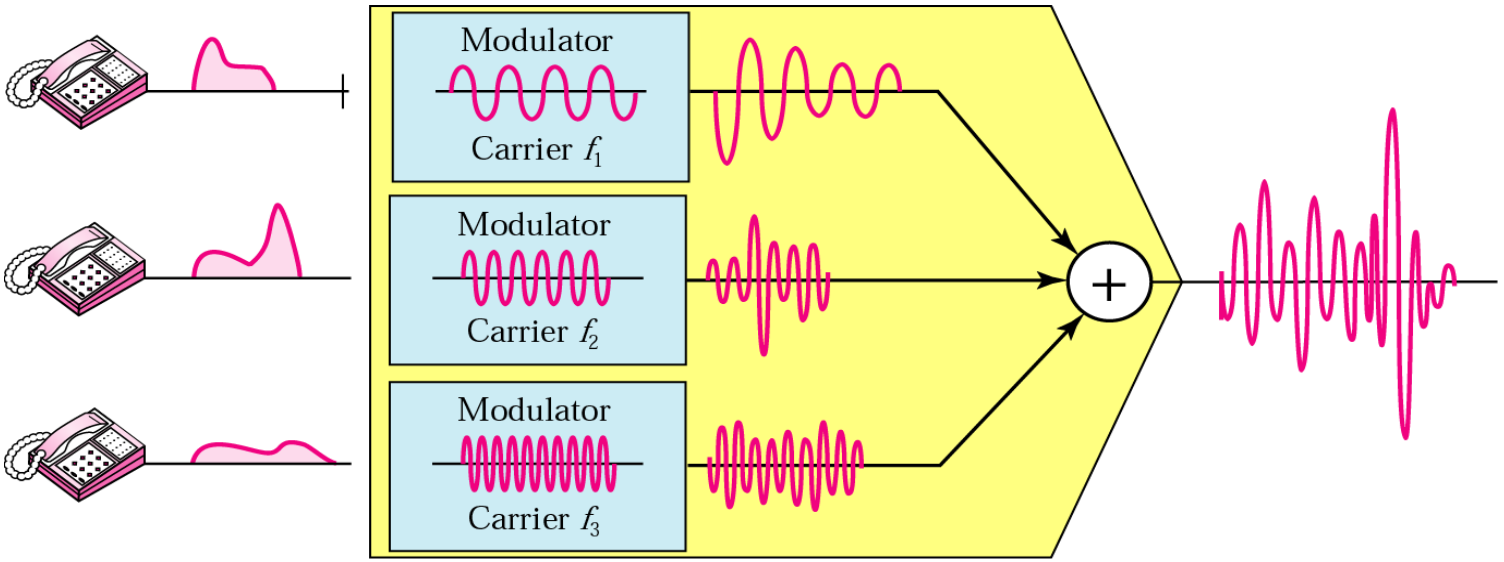
FDM - Multiplexing Process



- Each telephone generates a signal
- Signals are modulated onto different carrier frequencies
- Resulting modulated signals are combined into a single composite signal
- Composite signal is transmitted over a media link

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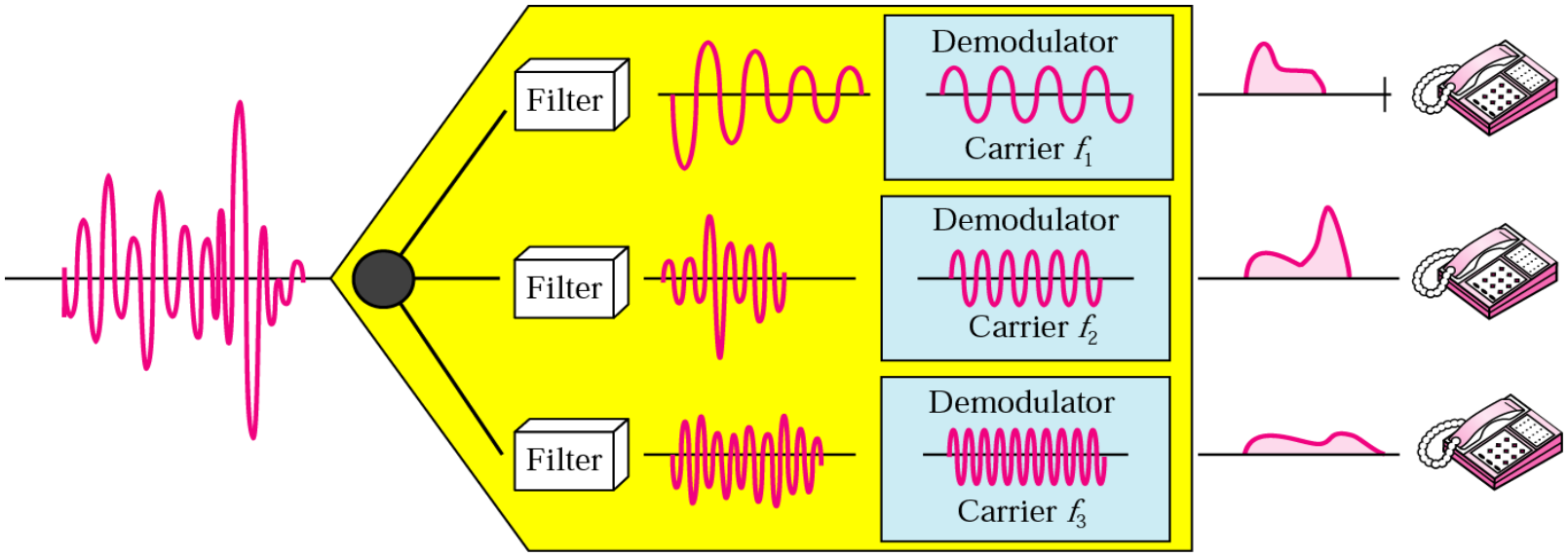
FDM - Demultiplexing Process



- Demultiplexer uses filters to decompose the composite signal
- Individual signals are passed to demodulator that separates them and passes them to receivers

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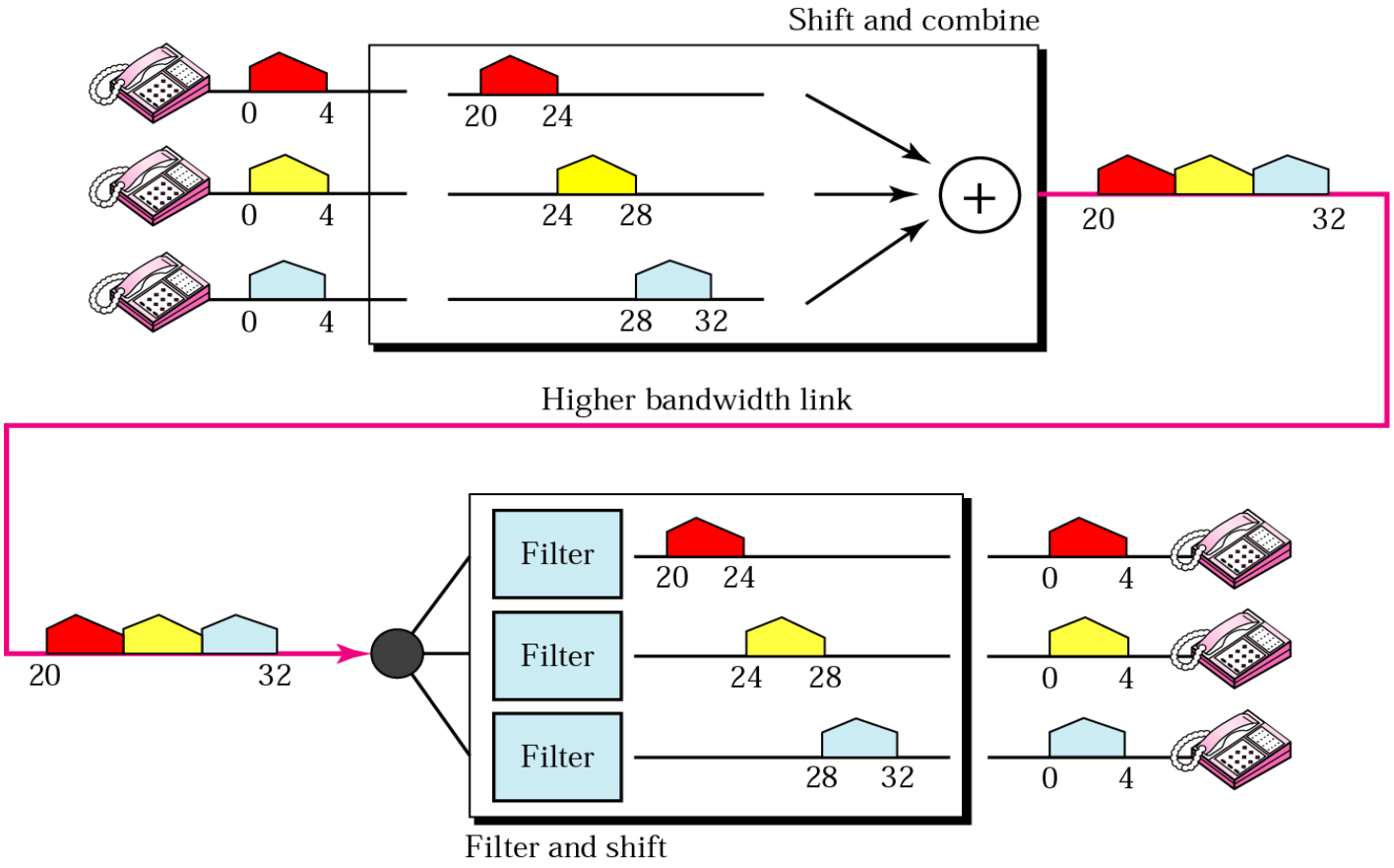
Example- combining three voice channels

Assume that a voice channel occupies a bandwidth of 4 KHz. We need to combine three voice channels into a link with a bandwidth of 12 KHz, from 20 to 32 KHz. Show the configuration using the frequency domain without the use of guard bands.



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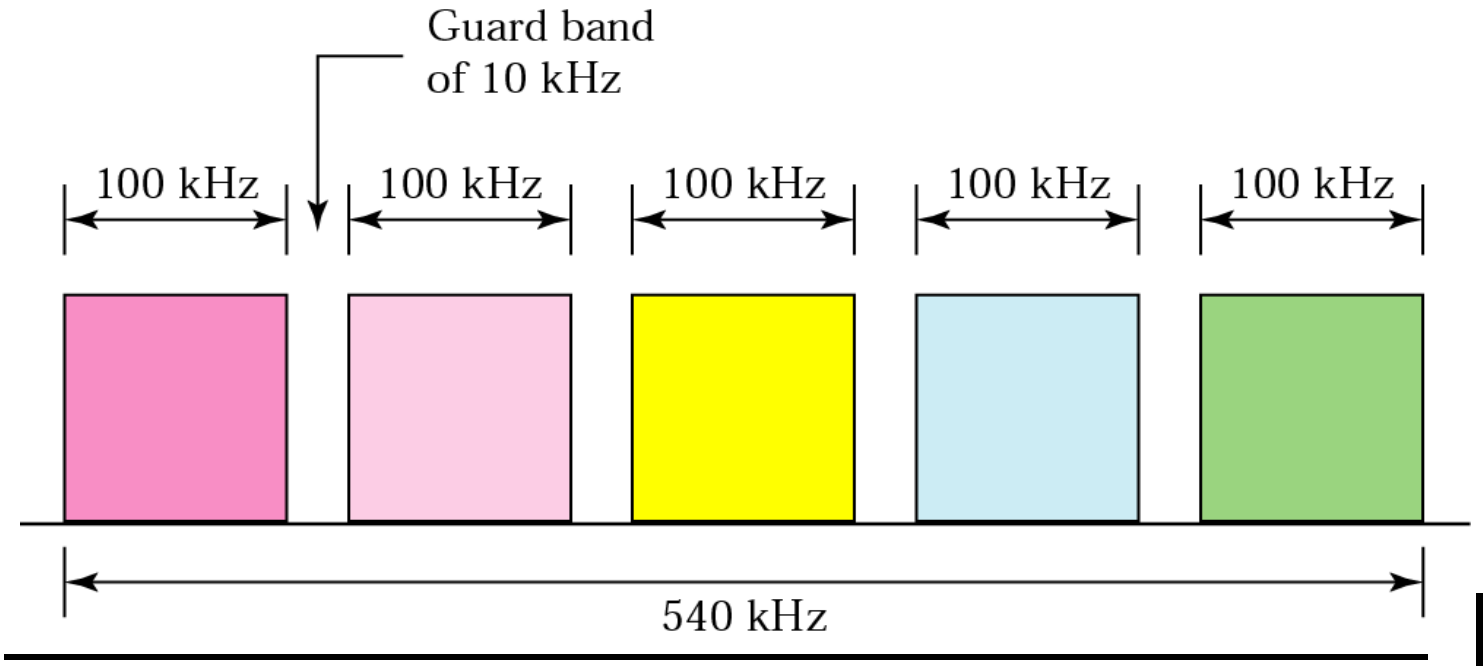
Example- Multiplexing channels with guard bands

Five channels, each with a 100-KHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 KHz between the channels to prevent interference?

For five channels, we need at least four guard bands. This means that the required bandwidth is at least

$$5 \times 100 + 4 \times 10 = 540 \text{ KHz},$$

as shown in Figure below



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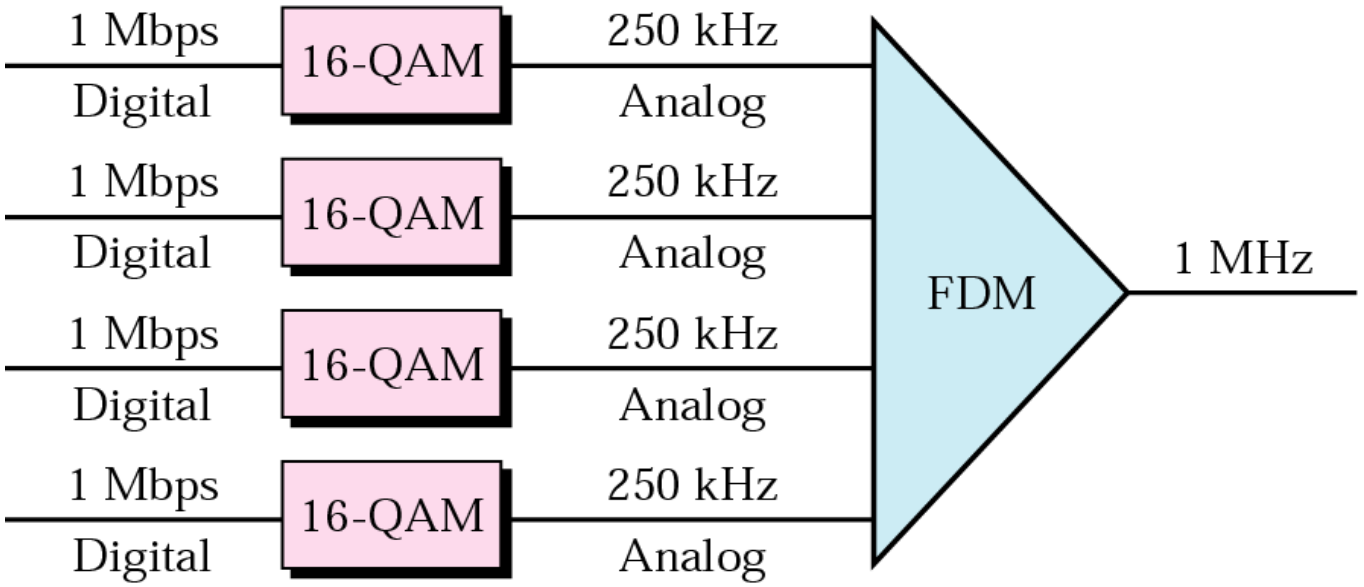
Example- Multiplexing Four Digital channels

Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration using FDM

The satellite channel is analog. We divide it into four channels, each channel having a 250-KHz bandwidth. Each digital channel of 1 Mbps is modulated such that each 4 bits are modulated to 1 Hz. One solution is 16-QAM modulation. Figure below shows one possible configuration. A 16-QAM signal has 4 bits per signal unit



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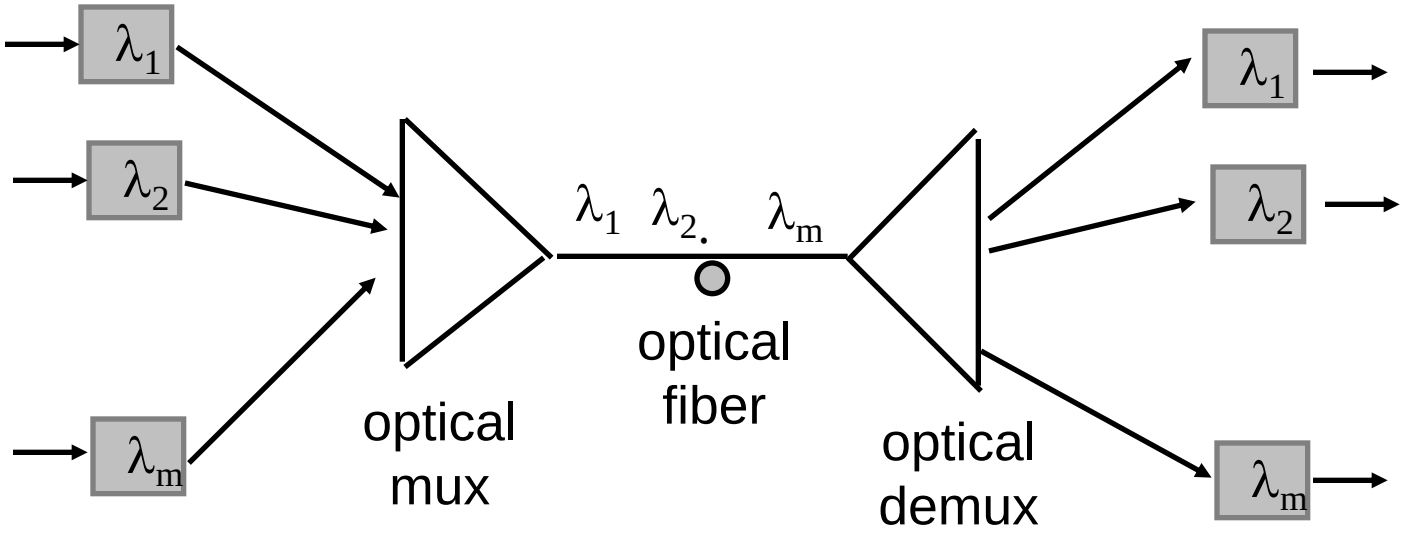
Wavelength Division Multiplexing



- WDM is an analog multiplexing technique to combine optical signals. Conceptually same as FDM.
- Different wavelengths carry separate signals
- Multiplexed into shared optical fiber
- Each wavelength like a separate circuit
- A single fiber can carry 160 wavelengths, 10 Gbps per wavelength: 1.6 Tbps!

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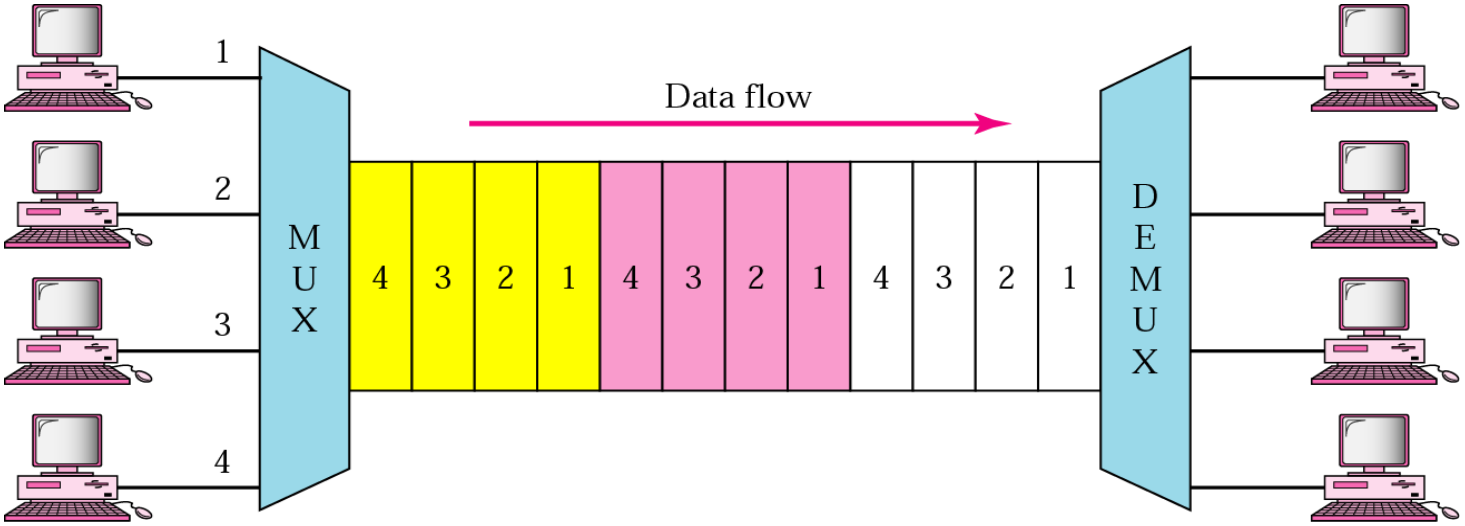
Time Division Multiplexing



- TDM is a digital multiplexing technique to combine data
- Instead of sharing a portion of bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link
- Allows several connections to share the high bandwidth of a link
- Time slots pre-assigned to sources and fixed
- Time slots allocated even if no data

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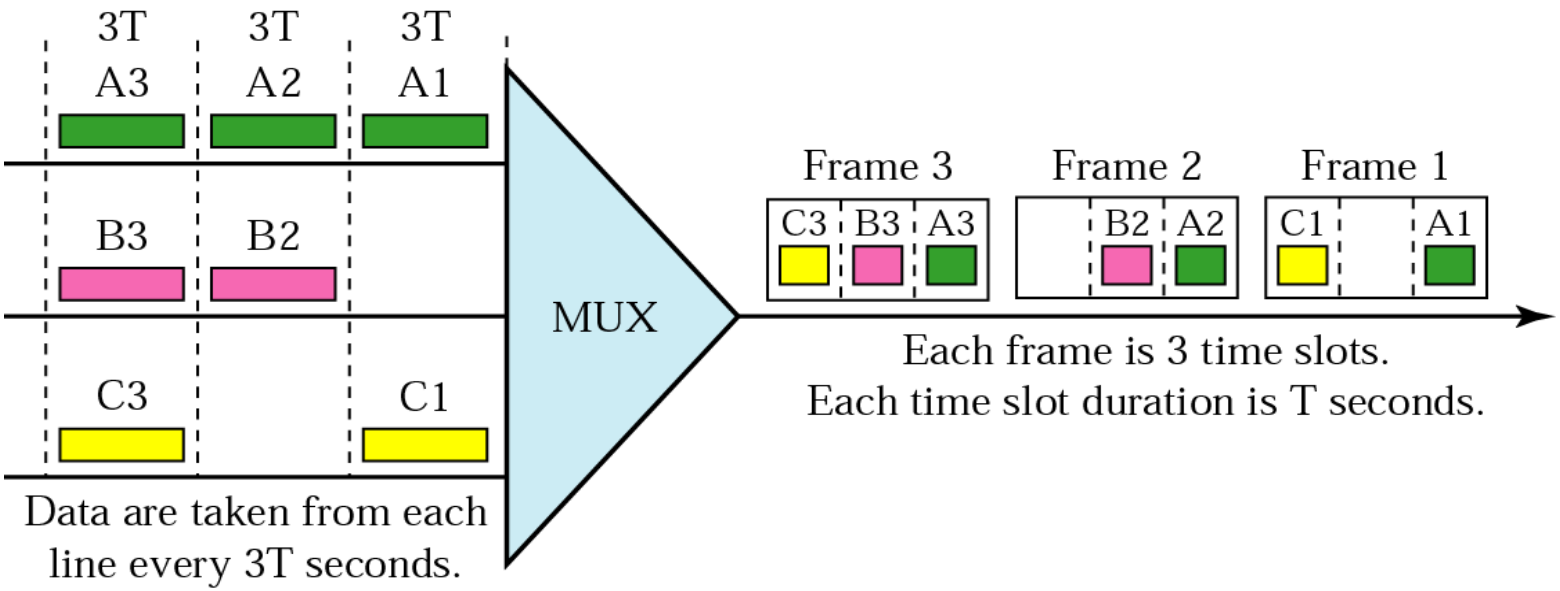
TDM Frames



- **Data rate of the link that carries n connections must be greater than or equal to the data rate of individual connections to guarantee the flow of data.**
- **Example:** Four 1-Kbps connections are multiplexed together. The transmission rate of the link is 4 times the rate of a connection – 4 x 1= 4 kbps

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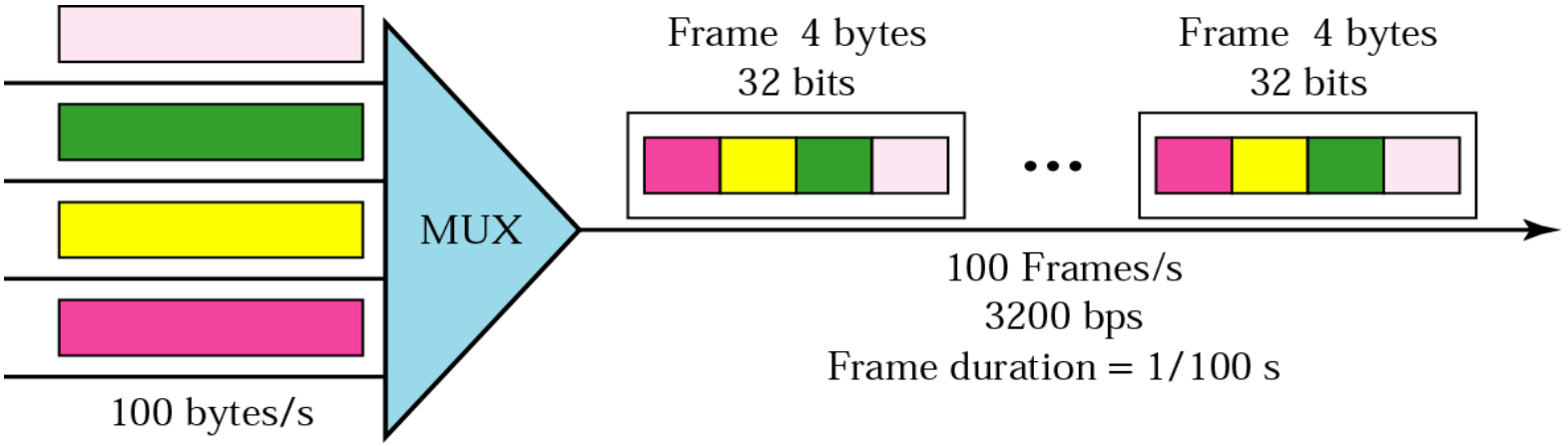
TDM Example

Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link



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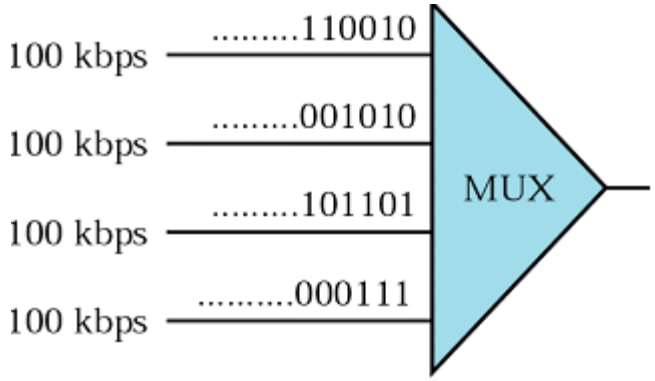
Another TDM Example

A multiplexer combines four 100-Kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?



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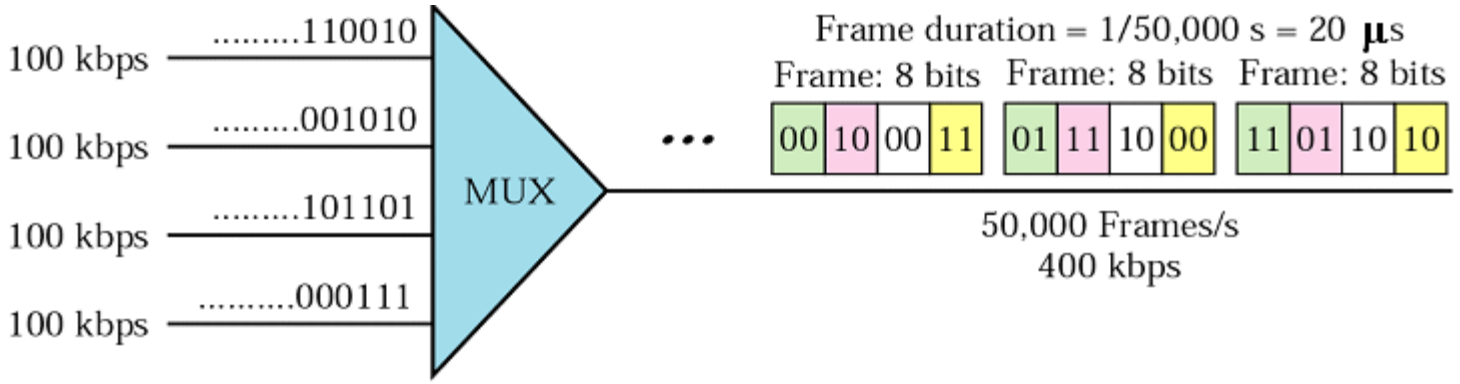

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TDM Link Control

- No headers and trailers
- Data link control protocols not needed
- Flow control
  - Data rate multiplexed line fixed
  - If one channel does not receive others continue
  - Empty slots
- Error control
  - Errors detected and handled by individual channel systems

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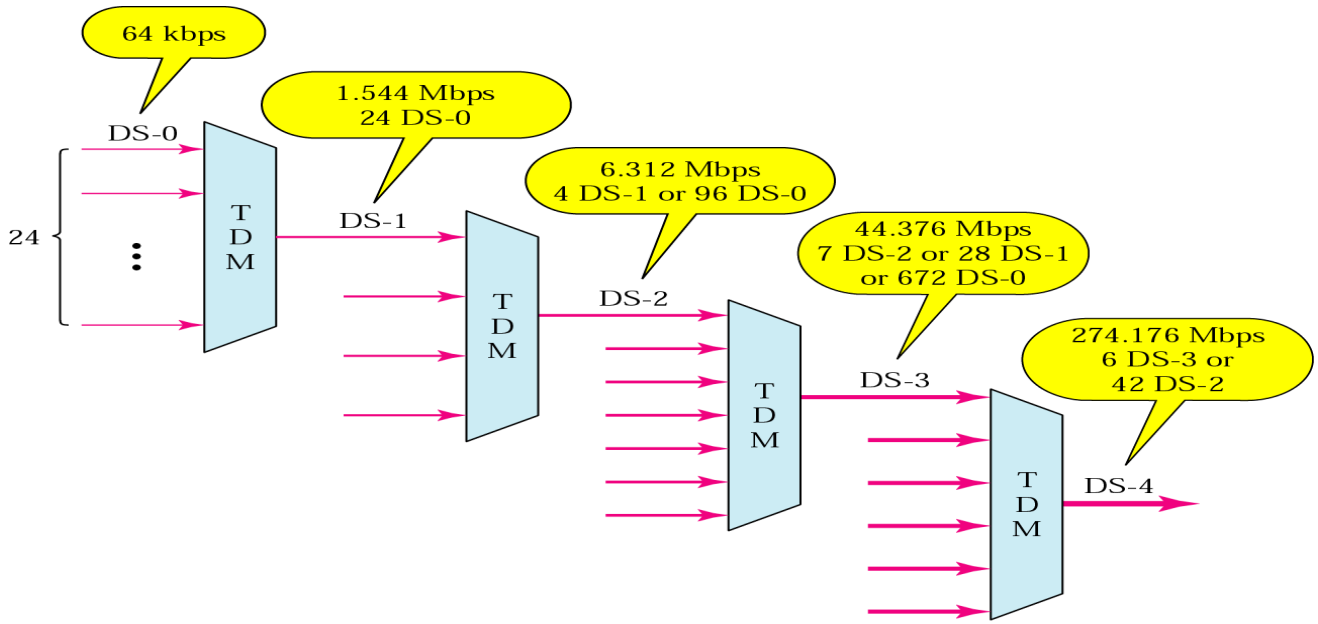
Digital Carrier Systems



- Hierarchy of TDM
- USA/Canada/Japan use one system
- ITU-T use a similar (but different) system
- US system based on DS-1 format
  - Multiplexes 24 voice channels
  - Each frame has 8 bits per channel plus one framing bit
  - 193 bits per frame

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DS and T lines rates

Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

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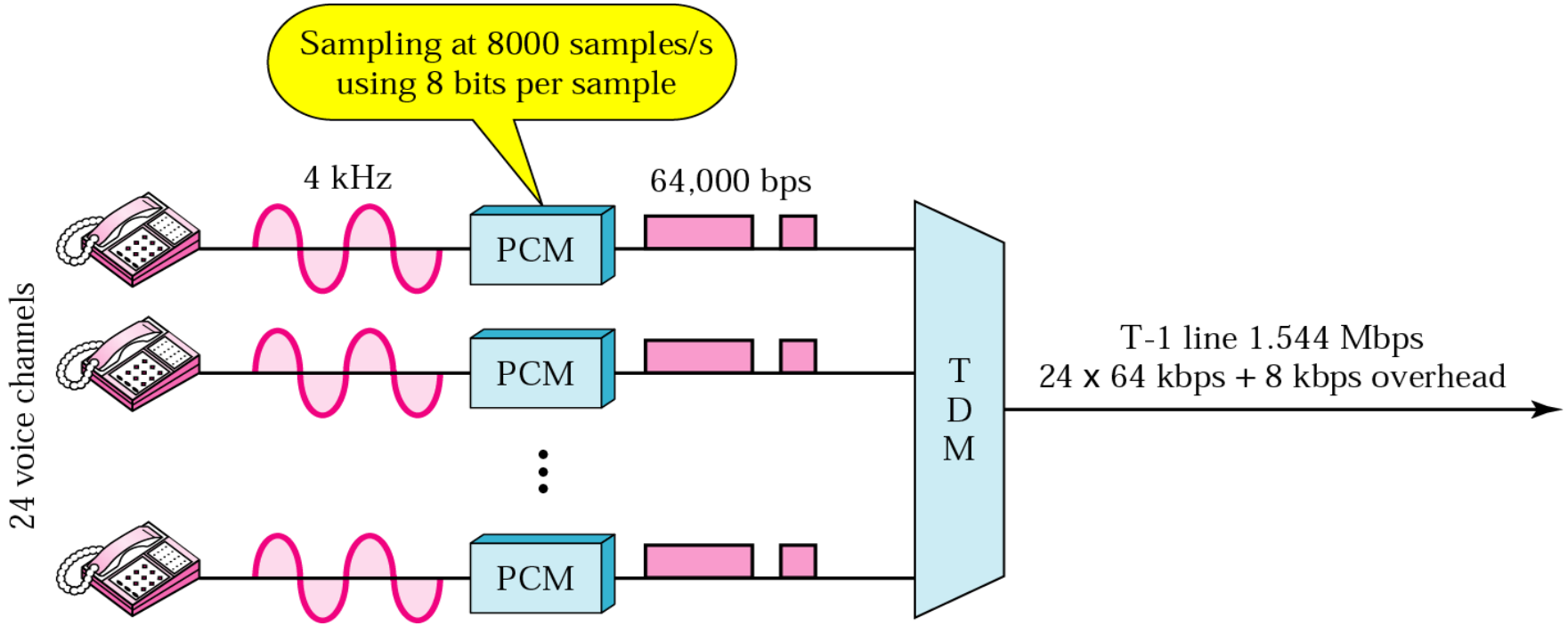
T-1 line for multiplexing telephone lines



- Digital telephone system uses TDM.
- PCM voice channel is basic unit for TDM
  - 1 channel = 8 bits/sample x 8000 samples/sec. = 64 kbps
- T-1 carrier carries Digital Signal 1 (DS-1) that combines 24 voice channels into a digital stream

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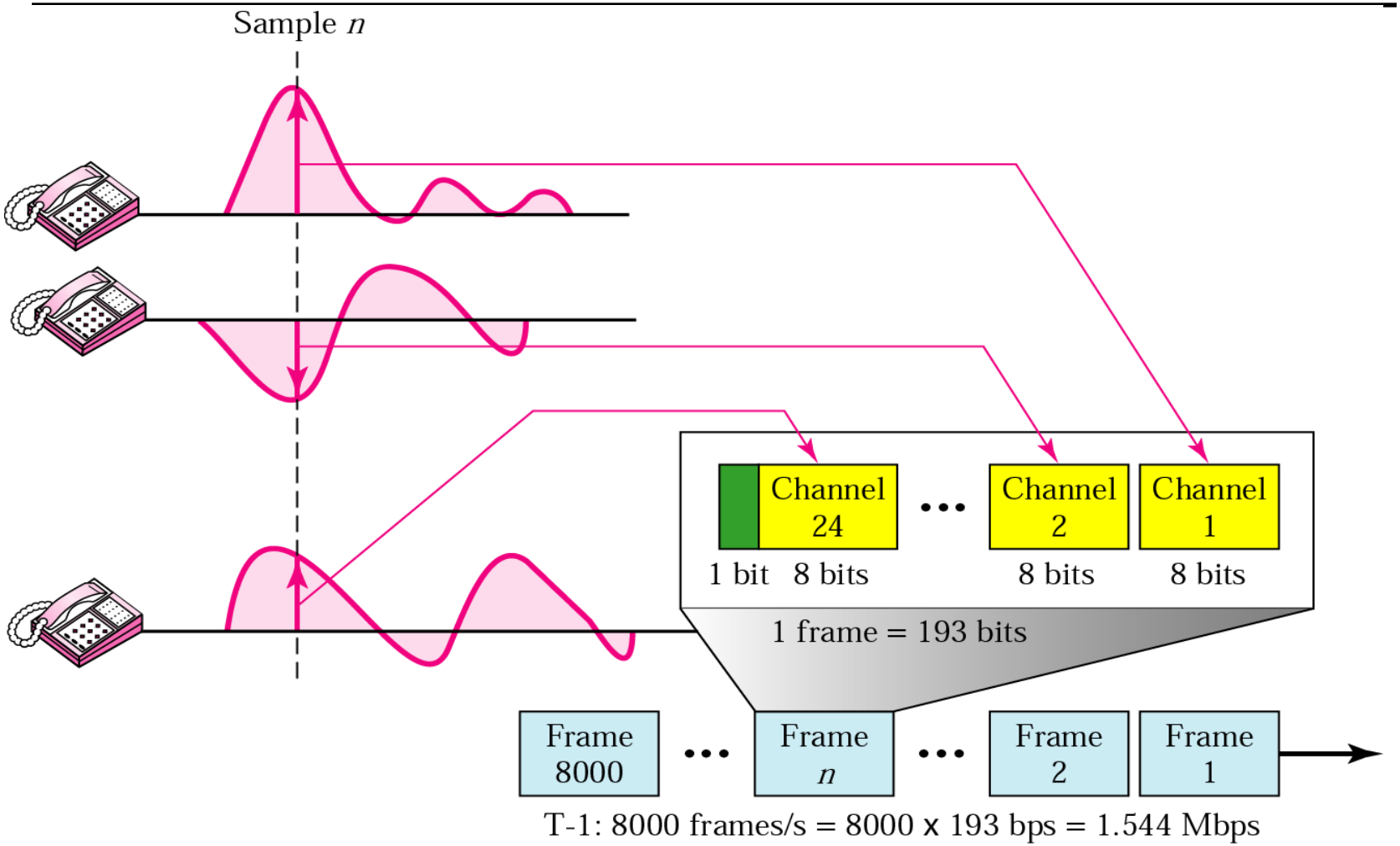
T-1 frame structure



Bit Rate = 8000 frames/sec. x (1 + 8 x 24) bits/frame
= 1.544 Mbps

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Statistical TDM

- In Synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- Multiplexer scans input lines and collects data until frame full
- Data rate on line lower than aggregate rates of input lines
- Performance
  - Output data rate less than aggregate input rates
  - May cause problems during peak periods
    - Buffer inputs
    - Keep buffer size to minimum to reduce delay

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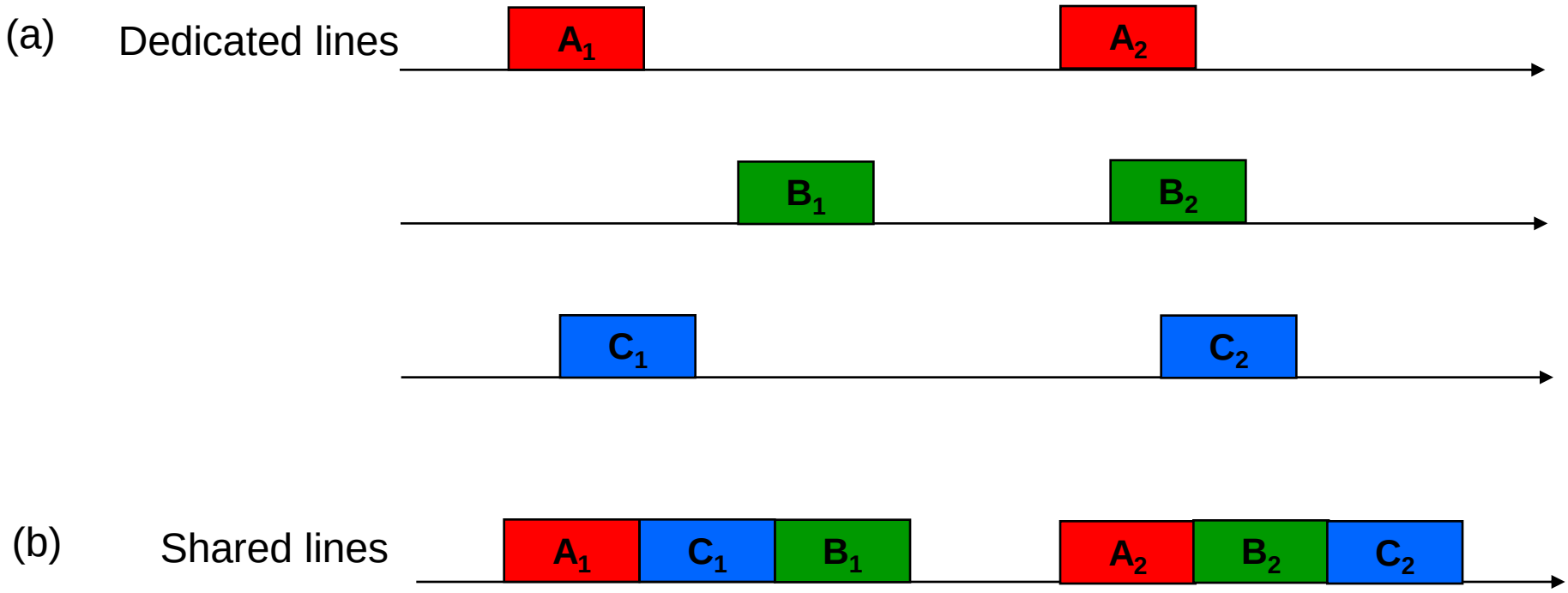
Statistical Multiplexing:Tradeoff Delay for Efficiency



- Dedicated lines involve not waiting for other users, but lines are used inefficiently when user traffic is bursty
- Shared lines concentrate packets into shared line; packets buffered (delayed) when line is not immediately available

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Summary

- In this lecture, we have understood:
  - TDM, FDM, WDM, statistical multiplexing
  - Examples of TDM, FDM

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Next Time

- We will know about
  - Flow control
  - Error control

- Suggested Reading:
  - Chapters 7 (Stallings)

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